LCA Case Studies

LCA Case Study of Zinc Hydro and Pyro-Metallurgical Process in China

Xiao Xiao[1,2]*, Xiao Songwen[1], Guo Xueyi[2,3], Huang Kelong[2] and Yamamoto Ryoichi[3]

[1] Changsha Research Institute of Mining & Metallurgy, Changsha 410012, P.R.China
[2] School of Metallurgical Science & Engineering, Central South University, Changsha 410083, P.R.China
[3] Center for Collaborative Research, University of Tokyo, Meguro-Ku, Tokyo, Japan 1538505

* Corresponding author (jx_xiao@yahoo.com.cn)

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Abstract

Goal, Scope and Background. China is one of the main producers of metallic zinc and its annual production has been becoming the largest in the world since the year 2000. To improve the environmental situation of zinc production in China, a life cycle assessment was performed for hydro and pyro-metallurgical processes, based on the case study of Zhuzhou Smelter and Shaoguan metallurgical plant, respectively.

Methods. The system is modeled into several sub-modules so as to identify the source of environmental impacts.

Results and Discussion. The main results of LCA study are summarized as follows: (1) Hydro-metallurgical process is superior to pyro-metallurgical process in GWP and inferior to pyro-metallurgical process in GER and ACP. (2) Compared with the advanced foreign zinc metallurgical process, the GWP, ACP and HME of the zinc metallurgical process in China are much higher. (3) In hydro-metallurgical processes, residue treatment and auxiliary processes are the main contributors of ACP and GWP, which are the key sub-modules, and should be improved. In pyro-metallurgical processes, the main sub-modules needing improvement are smelting, power and electricity generation. (4) Electricity is the main energy consumption in the hydro-metallurgical processes, accounting for 60% of GER. In pyro-metallurgical process, main energy sources are metallurgical coke and anthracite, both also accounting for 60% of GER.

Conclusions. According to the discovery of LCA study, three main measures to improve the environmental performance of zinc products were proposed: 1) Regulating the structure of energy sources of Shaoguan Smelter, 2) removing SO_2 in low concentration from flue gas by absorption with zinc oxide, and 3) adjusting the material structure of Walze rotary furnace.

Keywords: China; hydro-metallurgical process; life cycle assessment; pyro-metallurgical process; zinc

Introduction

Zinc is one of the main nonferrous metals, which are largely produced and largely consumed in the world. There are two main metallurgical processes, which are available for zinc production, i.e. the hydrometallurgical process and the pyrometallurgical process. At present, about 80% of total zinc production is performed using hydrometallurgical processes, and the remaining 20% of zinc is produced by pyrometallurgical processes. In China, Zhuzhou Smelter is the typical plant in which the hydrometallurgical process is adopted for zinc production, whereas Shaoguan Smelter adopts the Imperial Smelting Process for zinc production.

Life Cycle Assessment (LCA) is a useful and effective tool to address the environmental performances and potential impacts of a product throughout its life cycle (i.e. from cradle to grave) from raw material acquisition through production, use and disposal (ISO 1997) [1]. LCA provides a broad view by generating a model which links the industry to be assessed through all its material and energy resource flows to other environmentally significant processes in the wider industrial network. At the same time, a well-defined process life cycle model retains the power to relate potential environmental liability directly to specific unit operation in the industry which is being assessed [2].

In this study, a process-based LCA has been performed for the hydro and pyro-zinc metallurgical process based on Zhuzhou and Shaoguan Smelter in China, respectively. The purpose of this study is to highlight areas of the zinc metallurgical process, which contributes most significantly to potential environmental impacts, thereby identify the areas of potential improvement, and eventually provide a scientific basis for the improvement on resource and energy use as well as in emission control, and to ultimately implement its clean production for zinc metallurgical processes.

1 Goal and Scope

1.1 Function unit

Function Unit is the measure of performance of a product system. In this study, the function unit is defined as one ton of metallic zinc with a purity of 99.995%.

1.2 System boundary

The system includes all the main and auxiliary processes of the hydro-metallurgical process in Zhuzhou Smelter and the Imperial Smelting Process in Shaoguan Smelter. Because of the complexity of zinc metallurgical processes, the system is divided into several sub-modules in term of the following principles:

1) The modules should be independent from each other, so that the recycling material flows may be minimized.
2) Each module and its inner structure should be conformed to the administrative framework of the enterprise, so as to be convenient to collect and manage input/output data.

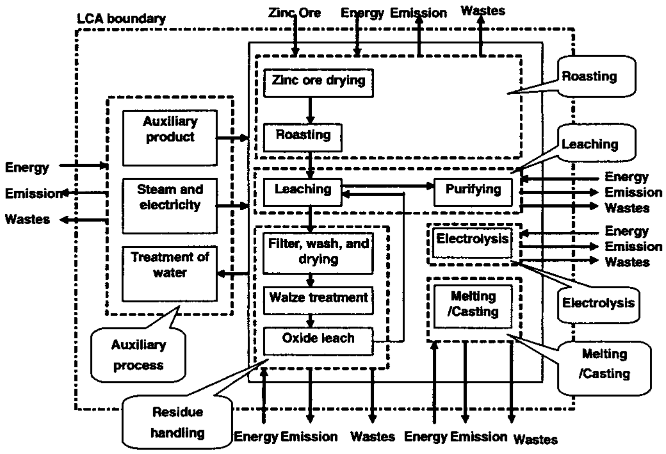

Fig. 1: The system boundary diagram of Zhuzhou smelter

Based on these principles, the hydro-process system boundary of Zhuzhou Smelter is modeled as in **Fig. 1**. The whole system is divided into six sub-modules: roasting, leaching, electrolysis, melting/casting, residue treatment and auxiliary process. For the pyrometallurgical process in Shaoguan Smelter, the sub-modules include sintering, smelting, zinc rectification, SiC production, power and electricity and transportation. This division allows for improved transparency in the mass balance, and helps to clarify the audit trail of environmental impacts back to their sources in the process. The mass flows being taken into account are those which directly flow to the environment, and thus have direct impacts, for example, the energy input and air emission. The 'internal' flows such as intermediate product flows between sub-modules are excluded from the assessment because they have no environmental impacts on the outer environment of the system.

1.3 Environmental impact categories

In the zinc metallurgical process, the environmental impacts such as noise and dust are excluded from consideration since they only have an effect on the inner environment of the system. The environmental impacts which must be taken into account are those effects on the outer environment of the system, for example, energy consumption, SO_2 and heavy metals emission, etc. Therefore, five kinds of environmental impacts were taken into consideration in this study, i.e. energy consumption, greenhouse gas emission, acid rain, heavy metals pollution and solid waste burden.

2 Inventory Analysis

2.1 Data collection

The original input/output data of this study, including material use, energy consumption, product and waste emissions, were collected from the tables of mass and energy balance, the annual report of environmental monitoring and the informative tables of waste emissions and treatment of corresponding enterprises. All these data are true and believable. Other necessary data were gathered and calculated according to the daily statistics of the actual production.

2.2 Principle for allocation

The input/output was allocated among the main products of Zn, Pb, and H_2SO_4, regardless of the very low yield products such as Cd and Ag. The metallic zinc is the dominant product in zinc metallurgical process, whereas Pb, H_2SO_4 and other products are its joint products. Thus, the allocation was done according to the methods of system expansion and substitution [3] (**Fig. 2**). That is, in Shaoguan Smelter metallurgical system, metallic zinc is responsible for the environmental impacts arising from sintering, smelting, zinc rectification, and co-production processes which include transportation, power and electricity, SiC production and waste disposal. In Zhuzhou Smelter hydro-system, metallic zinc is responsible for the environmental impacts arising from all the main and auxiliary processes except sulfuric acid production.

The allocation among the zinc series products such as zinc slab, HDG zinc alloy, die casting, and zinc powder, etc., was based on the elemental zinc contained in these products, because they are combined products of metallic zinc ingot [4]. That is, in the case of calculation, the product capacity was converted into the function unit according to the zinc content in each product.

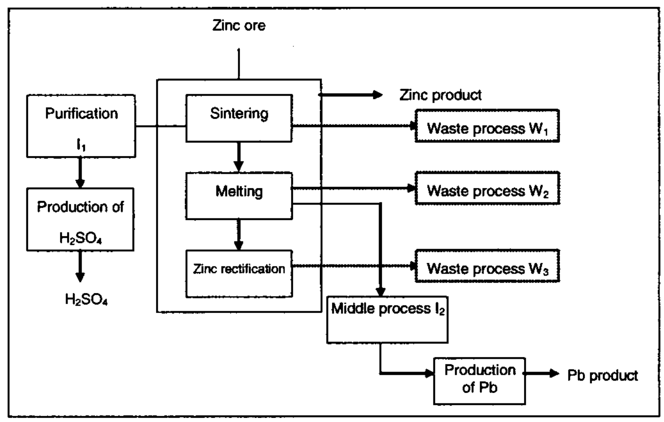

Fig. 2: System expansion and border of zinc and joint products

2.3 Method of calculation

The consumption of energy and raw materials per FU were calculated in terms of total consumption and zinc produced each year. The emission generated from the production process, which were relevant to the five specific impact categories, were also transferred as amount per ton of zinc. The CO_2 emissions per FU of different energy sources were converted from the carbon-based energy consumption according to its carbon content, because the concentrations/amounts of CO_2 were not measured in zinc metallurgical processes. The formula for the CO_2 amount calculation is:

$$C = \sum_{i=1}^{n} C_i = \sum_{i=1}^{n} G_i \times g_i \tag{1}$$

where,

- C is the total amount of CO_2
- C_i is the amount of CO_2 converted from each energy type
- G_i is the energy consumption of each type
- g_i is the conversion coefficient from each energy type to CO_2, see reference [5].

2.4 Inventory analysis results

Table 1 and 2 show part of the inventory data of zinc production in Zhuzhou Smelter and Shanguan Smelter, respectively. Full inventory data refers to reference [5] and [6], detailed analysis is discussed in the next section.

Table 1: The main inventory data of Zhuzhou smelter

Energy Consumption (/t Zn)

Energy (unit)	Electricity (kwh)	Water (t)	Coal powder (t)	Diesel oil (t)	Steam (t)	Coal gas (m^3)	Coke block (t)	Smoke coal powder (t)
Roasting	102.62	5.08		0.0005	0	69.29		
Leaching	73.18	1		2E-05	0.63	0		
Electrolysis	3346.41	0.689		1.3E-05	0.046	29.738		
Melting/ Casting	154.105	0.175		1.4E-05	0	36.691		
Residue Handling	129.09	2.82	0.57		0.37	594.81		
Auxiliary Process	30.04	6.48	0.18	4.94E-05	0.19	38.53	0.005	0.046
Total	3835.442	16.244	0.75	0.0006	1.236	769.059	0.005	0.046

Emission to Air

Emission (unit)	CO_2 (t/t Zn)	SO_2 (kg/t Zn)	Pb (kg/t Zn)	As (kg/t Zn)
Roasting	0.042	2.047	0.00296	0.0005
Leaching	0.0001			
Electrolysis	0.017			
Melting/Casting	0.022			
Residue Handling	1.499	16.781	0.0932	0.0152
Auxiliary Process	0.535	0.141	0.0007	0.0001
Total	2.115	19.117	0.0969	0.0158

Emission to Water

Emission	COD	Hg	Cd	As	Pb	Cu
Values (kg/t Zn)	0.583	4.3E-05	0.0026	0.001	0.018	0.005
Solid Wastes t/t Zn	**0.323**					

Table 2: The main inventory data of Shaoguan smelter

Energy Consumption (/t Zn)

Energy (unit)	Sintering	Melting	Zinc Rectification	SiC Production	Power & Electricity	Transpor-tation	Total
Metallurgical coke (t)		1.023			0.105		1.128
Petrolic coke (t)				0.003			0.003
Anthracite (t)					1.508		1.508
Soft coal (t)				0.0014		0.0073	0.0087
Soft coal powder (t)		0.076				0.011	0.087
Coal gas (thousand m^3)	0.404	0.407	2.42	0.014			3.247
Diesel oil (t)					0.0002	0.0006	0.0008
Gasoline (t)						0.0017	0.0017
Electricity (thousand kwh)	0.226	0.429	0.0549	5.327E-04	0.206	0.001	0.918
Water (thousand m^3)	0.0064	0.059	0.0065	7.906E-04	0.056	0.0008	0.13
Steam (t)	0.143	0.098	0.147	0.006	0.131		0.525
Pressurized air (thousand m^3)	0.165	0.369			0.007		0.542
Oxygen (t)	0.057	0.447	0.01	0.003	0.02	0.005	0.542

Emission to Air

Emission(kg)	Sintering	Melting	Zinc Rectification	SiC Production	Power & Electricity	Transpor-tation	Total
SO_2	9.325				1.669		10.994
Hg	0.0347						0.0347

Emission to Water

Emission	Pb	Zn	Cd	Hg	As	F
Values (kg/t Zn)	0.138	0.229	0.0080	0.00069	0.0019	0.149
Solid Wastes t/t Zn	**0.582**					

3 Impact Assessment

3.1 Eco-indicators

The Eco-indicators of Gross Energy Requirement (GER), Global Warming Potential (GWP), Acidification Potential (AP), Heavy Metal Equivalent (HME) and Solid Waste Burdens (SWB) are chosen for characterizing the effect of selected environmental impact category in the above section [7].

3.2 Method of eco-indicator calculation

Eco-indicators are determined by multiplying the equivalent factors with the corresponding inventory value. The equivalent factors used in this study are characterization value in Eco-indicator 95 developed by Pré consulting [8].

The Eco-indicator of the whole system is the sum of that of each sub-module. In principle, all the indicators must be calculated by that means. But in fact, the waste water effluented from each sub-module was drained into the wastewater treatment plant, where some of the heavy metals were removed. The data in the annually emission report is the ultimate amount or concentration of heavy metal effluent from the wastewater treatment plant. Therefore, only the total HME is calculated. The SWB is in the same case as HME.

3.3 Life cycle impact assessment result

The Eco-indicators of the zinc hydro-process of Zhuzhou Smelter and the pyro-process of Shaoguan Smelting in the year 2000 are shown in **Table 3**. The GER of Zhuzhou Smelter (2.692t energy/t Zn) is higher than that of Shaoguan Smelter (2.128 t energy/t Zn), but the GWP of Shaoguan Smelter is up to 5 times of Zhuzhou Smelter. The ACP of Zhuzhou Smelter is also higher, almost up to 2 times that of Shaoguan Smelter. There is no obvious difference in HME and SWB for either of the two processes.

The Eco-indicators of each sub-module of Zhuzhou Smelter and Shaoguan Smelter are shown respectively in **Table 4** and 5, respectively, from which the sub-modules mainly contributing to each Eco-indicator are addressed. The accurate analyses of the contribution of sub-modules to the total Eco-indicator is discussed in the following section.

4 Analysis and Discussion

The differences of Eco-indicators between Zhuzhou Smelter and Shaoguan Smelter mainly result from the different process adopted. It is reasonable that the GER of Zhuzhou Smelter is higher than that of Shaoguan Smelter. But GWP of Shaoguan Smelter is higher than that of Zhuzhou Smelter, because large amounts of 'dirty' carbon-based energy is used in the former, whereas electricity was used as the main energy instead in Zhuzhou Smelter. In general, the ACP of the pyro-process should be higher than that of the hydro-process, but in fact, the ACP in Zhuzhou Smelter is quite a bit higher than that in Shaoguan Smelter. This result indicates that Zhuzhou Smelter has not yet adopted effective measures to put SO_2 emission under control.

4.1 Comparison with the advanced zinc metallurgical process

Compared with the advanced zinc metallurgical process in foreign countries, there is a great difference in the environmental performance in both Zhuzhou and Shaoguan Smelter. **Table 6** shows the amounts of SO_2 and CO_2 emission from the zinc metallurgical process in Japan [9] and China. It can be seen that the total emissions of SO_x and CO_2 of the pyro-process in Shaoguan Smelter are about 2 times higher than that in Japan. The SO_x emitted hydro-process of Zhuzhou is almost up to 5 times that observed in Japan, although its CO_2 emission has no pronounced difference. Therefore, a reduction in the emission of acid rain gases such as SO_2 and greenhouse gas such as CO_2, and especially SO_2 abatement, is very important to improve the environmental profile of zinc production in the zinc metallurgical plants of China.

Table 3: The Eco-indicators of Zhuzhou and Shaoguan smelter

Eco-indicators (unit)	GER (tEnergy/t Zn)	GWP (tCO_2-eq/t Zn)	ACP ($kgSO_2$-eq/t Zn)	HME (kgPb-eq/t Zn)	SWB (t/t Zn)
Zhuzhou Smelter (Hydro-process)	2.692	2.156	18.969	0.137	0.323
Shaoguan Smelter (Pyro-Process)	2.128	10.926	10.994	0.202	0.582

Table 4: The Eco-indicators of sub-modules of Zhuzhou smelter

Eco-indicators	Roasting	Leaching	Electrolysis	Melting/Casting	Residue Handling	Auxiliary Process	Total
GER	0.057	0.110	1.374	0.068	0.749	0.334	2.692
GWP	0.042	0	0.054	0.021	1.450	0.589	2.156
ACP	2.047	0	0	0	16.781	0.141	18.969

Table 5: The Eco-indicators of sub-modules of Shaoguan smelter

Eco-indicators	Sintering	Melting	Zinc Rectification	SiC Production	Power & Electricity	Transportation	Total
GER	0.308	1.89	0.474	0.01	0.146	0.022	2.128
GWP	0.236	3.617	1.417	0.023	5.570	0.063	10.926
ACP	9.325	0	0	0	1.669	0	10.994

Table 6: SO_x, CO_2 emission of zinc metallurgical process in Japan and China

Emission	China		Japan	
	Pyro-process (Shaoguan Smelter)	Hydro-process (Zhuzhou Smelter)	Pyro-process	Hydro-process
CO_2 (t/t Zn)	10.926	2.156	3.39	1.75
SO_x (Kg/t Zn)	10.994	18.969	3.84	2.7

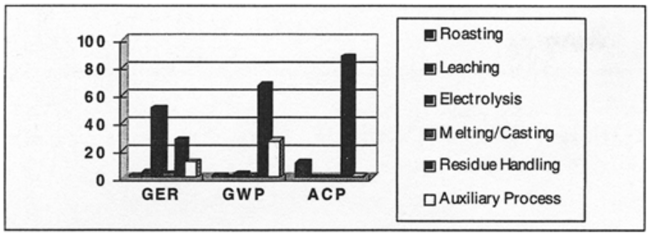

Fig. 3: The contribution of sub-models of Zhuzhou smelter

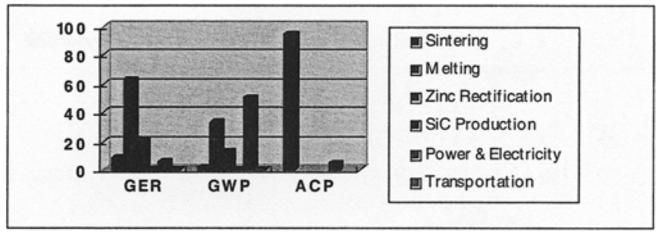

Fig. 4: The contribution of sub-model of Shaoguan smelter

Table 7: The main energy consumption in metallurgical process in Japan and China

Energy consumption	Pyro-process			Hydro-process		
	Coke (t)	Coal (t)	Natural gas (km^3)	Electricity (Mkwh)	Coke (t)	Coal gas (km^3)
Japan	0.784	/	1.422	3.888	0.067	0.001
China	1.131	1.605	/	3.823	0.569	0.734

4.2 The contribution of sub-modules

The contributions of sub-modules to the total Eco-indicators of Zhuzhou and Shaoguan Smelter were depicted in Fig. 3 and 4. The sintering, smelting and power & electricity are the main contributors to ACP and GWP in Shaoguan Smelter. The main contributors to ACP and GWP in Zhuzhou Smelter are the residue treatment and auxiliary processes. These are the key sub-modules needing improvement in Shaoguan and Zhuzhou Smelter.

4.3 The energy sources used in metallurgical processes

Four main energy sources in the pyro-metallurgical process of Shaoguan Smelter are metallurgical coke (33.34%), anthracite (32.78%), coal gas (17.48%) and electricity (11.29%), three of which belong to carbon-based energy, whose contribution to GER accounts for 85%. In the hydro-metallurgical process of Zhuzhou Smelter, the main energy source is electricity (58.11%), followed by coke powder (27.29%), coal gas (6.3%) and steam (5.7%). The contribution to GER of carbon-oriented energy is only 35%.

Table 7 displays the main energy sources used in the zinc metallurgical processes of Japan [9] and China. The amount of 'dirty' carbon-based energy used in Japan is much lower than that in China. The 'dirty' energy such as coal and coke is partly, in most cases wholly, replaced by 'clean' energy such as natural gas in Japan. For hydro-processes, the main energy in Japan is electricity, whereas coke and coal gas are hardly used. However, the coke and coal gas are often used as the main energy in China. It is worth noting that electricity power is generated from hydropower and natural gas in Japan, but it is mainly generated from thermal power in China. All of these result in the great difference in the emissions of acid rain gas and greenhouse gas from metallurgical processes seen in Japan and China.

5 Conclusions

LCA study for zinc metallurgical process has been conducted on Zhuzhou and Shaoguan Smelter with special intention to improving their environmental performance. The Eco-indicators, especially GWP and ACP, indicate that there has great difference between these two smelters with international zinc smelters in their environmental performance.

It is also found that energy consumption is one of the mainest factors to affect the total Eco-indicators of zinc metallurgical processes. The key sub-processes contribute most significantly to the total Eco-indicators of zinc metallurgical process are also identified in this study.

At last, three main measures to improve the environmental performance of zinc products were proposed: 1) Regulating the structure of energy sources of Shaoguan Smelter, 2) removing SO_2 in low concentration from flue gas by absorption with zinc oxide, and 3) adjusting the material structure of Walze rotary furnace.

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